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An overview of the biomass resource potential of Norway for bioenergy use

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ABSTRACT

This paper provides an overview of the Norwegian biomass resources for bioenergy use, bioenergy market and frame conditions through a comparison with Denmark, Finland and Sweden, which have a leading role in bioenergy production in the European Union. Although the contribution of renewable energy in Norway is among the highest in Europe (58%), mainly due to hydroelectricity, bioenergy has a low contribution to Norwegian energy supply (6%). As the experience from the other EU Member States showed, long-term, stable policies and relatively strong incentives are needed to initiate and build up a bioenergy market. In Norway, there is still a significant available potential for increasing the bioenergy contribution to the energy supply. The abundance and relatively low prices of energy (i.e. fossil fuels and electricity), in connection with the need of high investment costs, did not favour so far bioenergy production. Additional forest biomass may be mobilized in Norway by more intensive management of currently exploited forests. However, there are several limitations related to topography, accessibility and economics. The biomass resources and the full range of technologies available for heat or electricity generation both at small and large scale that can provide good opportunities for increased bioenergy production. The experience gained in Denmark, Finland and Sweden may be relevant for Norway, as well as for other EU Member States, where there is a deficit of mobilization of biomass resources and insufficient industrial integration of bioenergy with other forest-based sectors.

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1. Introduction

The European Union (EU) has set ambitious targets for renewable energy for the year 2020. According to the EU Directive 2009/28/EC [1] on the promotion of renewable energy sources, the EU Member States should increase the use of renewable energy to 20% of final energy consumption and 10% renewable energy in the transport sector by 2020. Bioenergy will play a crucial role in meeting the 20% target for renewable and GHG emission reduction by 2020. Biomass is expected to ensure at least 14% in the EU energy mix (SEC(2009)503 final) [2]. About 236 Mtoe[1] of biomass could be available in 2020 and 293.3 Mtoe by 2030 in the EU [3] while the EREC EU Technology Roadmap estimates that biomass can contribute by 235 Mtoe, covering 14.4% of the primary energy supply [4]. The Nordic countries have a good record in bioenergy production and use of forestry technologies that can be used as examples of good practice by other EU Member States. Denmark, Finland, Norway and Sweden already obtain a significant part of their energy supply from renewable sources. Norway is part of the European Economic Area (EEA) which allows Norway to participate in the single European market. The energy market in Norway is characterised by a low electricity price, the abundance of hydro power and large oil and gas reserves. The estimated share of renewable energy in Norway is 58%, of which hydro power represents the major share (50%), while bioenergy has a much lower contribution (6%). The Directive 2009/28/EC is EEA relevant, but no renewable targets are set yet for Norway. As this legislation applies to Norway under the EEA agreement, similar targets can be expected for Norway. This will require a 72% share of renewable energy sources in final energy consumption in 2020, compared with the present 58% share [5].

2. Frame conditions-energy policies and targets in Nordic countries

2.1. Renewable energy and bioenergy policy

All Nordic countries have supported electricity and heat generation from renewable resources for a long time. The use of by-products from the forestry industry for energy purposes has been prioritized in both Sweden and Finland, while in Demark bioenergy policies have supported the use of straw for cogeneration and district heating [6,7]. The White Paper on Climate Policy of Norway from 2008 provides for policy measures and emission reduction targets. Norway aims to become carbon neutral by year 2030. The objective of Norwegian strategy is to reach 100 PJ[2] (2.4 Mtoe) bioenergy by 2020, almost doubling the present figures. The strategy plan of 2008 outlines the measures to be taken to reach the bio-energy target in different policy areas, including carbon dioxide (CO_2) emission credits and CO_2 tax. An action plan is expected to support switching from fossil fuels to renewables for heating, including a ban on oil based heating in large public and commercial buildings [7,8].

Denmark has a long experience in the field of energy policy for promoting renewable energy sources. The long-term perspective of Denmark for sustainable energy development, Energi21 includes the objective of reducing CO_2 emissions by 20% by 2020 and by 50% in 2030 compared with 1998. Energy savings, better use of the energy resources and the contribution of 35% of the gross energy consumption from renewable energy by 2030 are the measures proposed to meet this objective [9]. Energi21 proposed an increased CHP generation based on straw, wood chips, biogas and conversion of heating plants from fossil fuels to biomass. The 2008 national energy agreement on "A Visionary Danish Energy Policy" set out the framework for Danish energy policy for 2011 and perspectives for 2025. It provides enhanced support for wind, biomass, biogas, waste and other renewables, such as photovoltaic and wave power [10].

Finland and Sweden were the first countries to introduce a carbon based tax for fossil fuels since the 1990s. The National Climate and Energy Strategy of Finland adopted in 2008 has established the policy measures up to 2020, and the perspectives for 2050. It targets at halting and reversing the growth in final energy consumption by 2020 compared to the baseline. A further decrease of at least one third of the final energy consumption was proposed for 2050 [11]. Finland has set the goal to increase the share of renewable energy sources up to 35–45% by 2020. The National Climate and Energy Strategy provides for a series of measures to be set in order to meet the requirements established by the EU Renewable Energy Directive 2009/28/EC [1]. They include an increase of the use of wood, waste, biogas, heat pumps and wind power [12]. This target shall be met by increasing the use of forest biomass and by increasing the area for energy crops cultivation. The Action Plan for Renewable Energy Sources in Finland requires reaching the renewable energy targets of 25% by 2015 and 40% by 2025. A policy objective is to expand renewable energy in combined heat and power generation in district heating systems and biofuels in the transport sector [6,13]. Energy taxes apply in Finland on transport and heating fuels and electricity. In heat generation, biomass is not taxed. Fuels used for electricity generation are not taxed, but an electricity tax is imposed on the consumption of electricity. Special rules apply for reducing the tax burden for industry. A tax rebate applies for wood based electricity. The energy taxation has rendered the consumer prices of heating oils and coal more expensive compared to wood fuels [11].

Sweden has ambitious environmental objectives, set in 2008, to decrease the GHG emissions by 40% by 2020 in comparison with 1990 levels. In the long term, Sweden aims to become carbon neutral by 2050 [13,14]. Sweden has an ambitious strategy to break its dependency on oil by 2020 through the increased use of renewable energy and energy efficiency measures. A comprehensive policy mix combined with tradable green electricity certificates as the key mechanism to increase the use of renewable energy. This system also creates an incentive to invest in the most cost-effective solutions [7,15]. The energy taxation system includes taxes on fuels and electricity, on carbon dioxide, sulphur and nitrogen oxide emissions. The carbon tax, introduced in Sweden in 1991, is imposed on the emitted carbon dioxide from all fuels except biomass and peat. In 2008, the carbon dioxide tax was 105 öre/kg of carbon dioxide (100 öre = 1 SEK), the sulphur tax was SEK 30/kg of sulphur emission from coal and peat, and the tax on the emission of nitrogen oxide was SEK 50/kg of nitrogen oxide [14]. The general energy tax is levied on most fuels, based on their energy content. The taxes vary depending on whether the fuel is being used for heating or as a fuel for transport, whether it is used by industry, households or energy generation. Fuels used for electricity production are not taxed. Electricity is taxed at the consumption level. It is possible

[1] Mtoe – 1 million tonnes of oil equivalent.
[2] 1 PJ = 10^{15} J.

for companies enrolled in an energy efficiency improvement programme to receive full tax rebate [16].

2.2. Renewable energy and bioenergy targets

As members of the European Union, Denmark, Finland and Sweden should comply with the EU climate and energy targets for increasing the share of renewable energy in the gross final energy consumption to 30% for Denmark, 38% for Finland, and 49% for Sweden, for reaching the 10% share of renewable energy in transport in each country and reducing the greenhouse gas emissions by at least 20% below 1990 levels by 2020 [11].

In 2006, Norway established a national target for increasing renewable energy production and energy saving equivalent to 144 PJ (3.4 Mtoe) by 2016. In comparison, the total domestic energy consumption was approximately 810 PJ in 2008 [8]. A separate target of 14.4 PJ (0.34 Mtoe) was set for heating based on renewable energy, including heat pumps and waste heat, and 10.8 PJ increased production of wind power. The aim is to promote the development of district heating through investment subsidies and support programmes [7,8]. The national target for reducing GHG emissions from agriculture by 2020 has been set to 1.1 Mt CO_2. Anaerobic treatment of manure is the major contributor to this target accounting for 0.5 Mt CO_2. The manure should be co-processed with food waste. This target means that 30% of the manure will be used in biogas plants with 600,000 tonnes of food-waste. The biogas produced would represent about 3.6 PJ bioenergy [17].

The renewable energy targets in Denmark are among the most ambitious in the EU: renewable energy must account for 30% of final energy consumption by 2020 (the sixth highest in the EU after Sweden, Latvia, Austria, Finland and Portugal). In 2008 "A visionary Danish energy policy" set the objective to reduce the use of fossil fuels by at least 15% by 2025 compared to 2007, and to maintain the total energy consumption at its current level. The use of renewable energy should be increased from 17% in 2005 to 20% of energy consumption in 2011 and at least 30% of energy consumption by 2025 [15,18].

Increasing the use of renewable energy by at least 25% by 2015 and 40% by 2025 is a key objective of Finnish energy policy. The Action Plan for Renewable Energy Sources requires renewable energy targets of 25% by 2015 and 40% by 2025. As bioenergy represents 95% of renewable energy in Finland, this target primarily required the increase in the biomass contribution to heat and power production [7,12]. Sweden should increase its share of renewable energy, in the final energy consumption, from 34% in 2008 to 49% by 2020, the highest share in the EU. The energy policy adopted in 2009 in Sweden includes a target to reach at least 50% of the energy mix from renewable energy sources by 2020. The objective in the electricity sector is to increase green electricity production by 25 TWh from 2002 to 2020. Most of it will be generated from onshore and offshore wind power, which should reach 30 TWh electricity by 2020, from the present 2 TWh [16].

2.3. Support schemes

Various support schemes, grants and programmes are common instruments in the Nordic countries for the promotion of bioenergy production [15]. The small incentives provided until now and low electricity prices did not favour the production of biomass electricity in Norway. Nowadays, there are several support measures for the development of bioenergy. Investment subsidies and support programmes were set for the development of district heating networks and the promotion of bioenergy in district heating. Investment subsidies of 20–40% can be provided for heating [8]. In Denmark, the Biomass Agreements starting from 1993 have been crucial for the large scale deployment of bioenergy production using straw and wood chips for heat and power generation. The high cost of fossil fuels has favoured the increase of biomass use for heat and electricity production. Subsidies for electricity produced by combined heat and power (CHP) plants are provided depending on fuel type. Subsidies for onshore wind, biomass and biogas production were increased. There are various subsidy schemes for doubling the forest area in Denmark over the next 80–100 years from the current 490,000 ha [9].

The support for renewable electricity is provided in Denmark in the form of a premium and as a fixed feed-in tariff. The renewable electricity producers receive a variable bonus, which is paid on top of the market price, depending on the market price and the statutory maximum [10,15]. The generation of renewable heating and cooling is supported by means of tax exemptions. Biomass is exempted from CO_2 tax. Grants were provided for co-financing large-scale development programmes to promote the use of second-generation biofuel technologies and to establish large scale research and demonstration plants for second generation biofuels in Denmark. Since 2005, biofuels are exempt from the CO_2 tax imposed on petrol and diesel for transport [18].

In Finland, electricity generation from renewable sources is promoted through subsidies for investments and electricity tax refunds. Support is provided for renewable energy projects, energy investment studies (40–50%), wind and solar energy (40%), energy conservation, renovation and modernisation (30%) and for innovative projects 40%. The construction costs of renewable energy plants are co-financed with grants up to 30% for wood plants for energy production and biogas. Direct investment support is provided for individual biomass heating installations. Grants are provided for aforestation, harvesting of energy wood, forest recovery and fertilisation. From 2008, a subsidy for biogas use for electricity production was planned, if production is based on agro-biomass, slaughter waste, manure and municipal waste. A feed-in tariff applies to electricity produced from peat in large power plants [11,12]. Feed-in tariffs are considered for electricity from wind power, biogas and small CHP [7,15]. In Finland, a tax applies on electricity suppliers, which they pass on to end consumers. A tax refund is granted to the suppliers of renewable electricity. Taxes on heat are calculated on the basis of the net carbon emissions of the input fuels and are zero for renewable energy sources [12]. No support mechanisms are in place in Finland for first generation biofuels for transport, but research projects are funded for developing second generation biofuels [15].

Sweden promotes renewable energy through various instruments, such as grant schemes, fiscal mechanisms and programmes. The energy tax and CO_2 tax exemptions on bioenergy along with the green certificates introduced in 2003 have contributed to the growth of bioenergy production [7,15]. A support system applies since 2003 for renewable electricity production, based on a quota system and electricity certificates. Since 2004, electricity produced from peat in cogeneration is also eligible for certificates [16]. Investment grants are available in Sweden for the replacement of oil heating systems by district heating, heat pumps, or biomass boilers. Biomass, solid waste and peat use for energy production are tax exempt. District heating is supported through various schemes. Grants are provided for the extension of existing district heating systems and for switching from oil to district heating or heat pumps [14]. The investment aid is provided to district heating using bioenergy. Investment subsidies are given to all renewable technologies up to 30% of the investment cost. Renewable heating is supported through energy taxes on fossil fuels. Tax refunds are provided if households switch to renewable sources [19]. Energy and CO_2 taxes apply to transport fuels in Sweden. Biofuels are exempt from the tax on petroleum products and from the tax on CO_2 [16]. A range of measures, such as grants, obligations and programmes, contributes to the increased use of biofuels for transport [7,15]. There is an

obligation for large filling stations to provide biofuels. A subsidy is granted for investment in filling stations supplying biogas and other renewable fuels: There is a subsidy for biofuel cars, hybrid cars etc. [14,19].

3. Biomass resources in Nordic countries

3.1. Forestry resources

Forest biomass is the major source of bioenergy in Norway, followed by waste used in district heating. Forests cover 12 million ha, which is 37% of the land area, with a growing stock of 910 million m^3. From an annual growth of about 25 million m^3, less than half (44%) is harvested annually [13]. The standing stock and annual increment have been increasing the last 70 years.

The most important biomass resources in Norway are firewood, wood chips, logging residues, thinning residues and stumps from clear cuttings. At present, these resources are used to a limited extent due to environmental or economic considerations [7,20]. In addition, much of the unused resources are available in remote areas, along the coast, with rather steep terrain and poor infrastructure. Norway is an important importer of wood, mainly pulpwood and wood chips for pulp and paper production, from Russia and the Baltic States. A small share of the imported wood is used for energy production, either directly as fuel wood or indirectly as by-products such as bark, sawdust and black liquor [8]. Hence, forest biomass has an estimated sustainable potential for bioenergy production between 86 and 108 PJ [5,8]. The sustainable potential of biomass for energy production is estimated between 117 and 140 PJ [7,8].

Unlike other Nordic Countries, Denmark is not rich in forest resources, with around 490,000 ha covered by forest representing about 10% of land area [9]. Biomass for energy production comes from forest chips, firewood, wood residues and wood pellets and agricultural residues, mainly straw. Wood is produced from willow crops in short rotation forestry on only approximately 2000 ha. The Danish resources of biomass for energy production were estimated at 147–165 PJ/year, including forest residues, firewood, wood pellets, agricultural residues, biogas, waste and energy crops [10]. The European Environment Agency (EEA) estimated the sustainable biomass potential at 105 PJ, with the major contribution of wastes (92 PJ) and forest residues (8.4 PJ) [3]. About half of biomass resources are presently used. The main part of wood resources comes from wood chip sourced from thinning of young tree plantations or from a considerable import of wood, primarily in the form of wood pellets [9]. Denmark is also the world's highest importer of wood pellets, with about 925,000 tonnes of wood pellets imported in 2008 from the Baltic States, Canada, Russia and Germany [21].

In Finland, forests cover 23.3 million ha (76% of land area), having a growing stock of 2163 million m^3. From an annual growth of 82 million m^3 felling amounts to 64 million m^3, representing 78% of the annual increment, which is among the highest in Europe [13]. Nevertheless, Finland is one of the world's largest importers of raw wood. A significant share of wood fuels used in the forest industry originates from imports, about 21% of wood used in 2007 [11]. The EEA estimates the Finnish biomass potential to be 402 PJ/year (9.6 Mtoe), of which 71 PJ will come from forestry by 2030 with the main resources from black liquor and wood waste [3,7]. The technical potential of forest fuel was estimated at 82–144 PJ by the Finnish Forest Research Institute, and the techno-economical potential at 86 PJ. Less than a quarter of the production potential is used, mainly due to economical and geographical constraints [7]. Almost 80% of bioenergy is generated in the wood industry from wood by-products and residues. The wood by-products and residues from the forest industry are fully utilised [9]. As the industrial use of wood and the production levels in the forest industry is expected to decrease, the potential for the use of wood residues and by-products from forest industry are likely to decrease. However, some assessments indicate that biomass supply from forests in Finland, mainly as wood chips from logging residues, stumps and small energy wood will increase [13].

Sweden is a country rich in forest resources, with 30.8 million ha of forest and a growing stock of 3191 million m^3. From an annual increment of 101 million m^3, 77 million m^3 are currently harvested, representing 76% of the annual growth [13]. The estimates of biomass potential in Sweden by 2020 vary between 544 PJ and 583 PJ. The forest biomass can have the highest role for bioenergy production, between 457 and 530 PJ. A much lower contribution is expected from agriculture (4–28 PJ) and waste (15–35 PJ) [7,13]. The EEA estimated the Swedish biomass potential to be around 544 PJ by 2020, of which 100 PJ from forestry, 298 PJ from wastes and a limited amount of 46 PJ from agriculture [3,7]. In Sweden, round wood is imported in the form of pulp wood and saw logs mainly from the Baltic States and Russia [16]. A small portion of the round wood import consists of energy wood for direct use. Table 1 shows the range of the biomass potential in Nordic countries [7,8,13].

3.2. Agriculture resources

Biomass from agriculture plays a minor role in the energy supply in Nordic countries, despite a long experience and efforts in research and development, and economic incentives [7]. The agricultural sector is limited in Norway. Agricultural land covers about 1 million ha or 3% of the total land area of Norway, of which 64% are grasslands and meadows, 31% cereals and oil seeds and organic farming constitutes 4% of the total area [5,22]. The area of arable agricultural land per 1000 inhabitants is smaller in Norway (186 ha) than in Sweden (299 ha) and Denmark and Finland (about 420 ha). Nevertheless, the figures are even lower in Germany and Austria (about 150 ha), in UK (95) and in the Netherlands and Switzerland (55 ha).

Currently, bioenergy production from agriculture is limited to a marginal supply of cereal straw and other crop residues [5,8,13]. Only 4 farm based biogas plants are so far in operation. Four new plants have been planned, of which some are for co-processing livestock manure and food waste. More new biogas plants are expected due to the government's climate target [17]). There are 20 biogas plants treating sewage sludge and 5 plants using food waste. The digestate is mainly used as fertiliser in agriculture [23]. The Norwegian policy does not favour the use of agricultural land for energy crops. This means that most bioenergy from agriculture will continue in the short term to be based on wastes and residues from crop production.

Some estimates of the agricultural potential in Norway show values from 9 PJ to 19.8 PJ. Straw and crop residues can contribute to a limited extent to bioenergy, up to 16 PJ. The contribution of energy crops, such as miscanthus, reed canary grass and other perennial grasses, or willow and poplar for bioenergy production might be between 3.6 PJ and 11 PJ [13,22]. The organic fraction of waste can also be used for energy purposes representing approximately 50% of the waste. Norway has set a goal to recycle 80% of the waste, and from 2009 it is not allowed any more to landfill biodegradable waste. This means that the use of waste for energy is expected to increase [5,6,24].

The Danish biomass potential, apart from wood chips, consists mainly of straw, manure, biogas, landfill gas and waste residues from crop production and food industry. The biomass potential available for energy production is estimated at 147–165 PJ [10] while EEA estimated the sustainable biomass potential at 104 PJ, with the main contribution of agricultural crop residues, mainly straw, manure and other agricultural wastes [3,22]. Wood

Table 1
Estimation of the range of biomass potential in Nordic countries [PJ].

	Denmark	Finland	Norway	Sweden
Forest sector	37–40	158–325	88–124	457–530
Black liquor		144–161		142–162
Wood residues	6.5	80–140	37–84.	48–150
Logging residues	5–37	108	14–30.	72–250
Firewood	19	50	37–84	44–72
Agriculture	55–87	23–29	9–19.8	4–28
Agri-residues	6.6–31	4–9	9–16	4–14
Energy crops	48–56	19–29	3.5–11	4–14.
Waste	22–30	8–10	11.9	15–35
Industrial waste			2.9	9–15
Municipal waste	30		9	9–25
Biogas	22–40	8–10	8–15	
Range of biomass potential	147–165	359–460	104–167	554–583

resources are almost completely used but only a part of the agricultural biomass resources are used (around half of straw resources and one tenth of biogas resources), leaving a considerable potential available [9].

The agricultural area of Finland is quite substantial, with 2.3 million ha. The contribution of agricultural biomass to energy production is reduced. However, there is some potential to increase the use of biomass from agriculture for bioenergy or biogas production, up to 23–29 PJ [14 = 13, 22]. Cereal straw, energy crops (oilseed crops and reed canary grass) and various wastes such as municipal solid waste, residues from the food industry or landfill gas can contribute to energy production. According to the estimates of the Finnish Ministry of Agriculture and Forestry, about 150,000 ha of land could be used for the cereals and oilseeds cultivation for biofuel production and 50,000 ha for reed canary grass. The goal to reduce the amount of landfilled waste could increase the amount of waste available for energy by 800,000 tonnes [22].

The agricultural area of Sweden is substantial, with 3.1 million ha. Biomass from agriculture currently contributes approximately 3.6 PJ to the energy supply, mainly from oilseeds, straw and energy crops and primarily willow. The land used for the production of biomass for energy purposes covers around 266,000 ha. The bioenergy potential from agriculture is estimated at 4–28 PJ, which is expected to come from agricultural residues and energy crops with 15–35 PJ to come from various waste and residues [13,22]. The estimates of land availability for bioenergy production range from 400,000 ha up to 2,000,000 ha with the contribution of agriculture to energy production of 108–126 PJ, from agricultural residues and energy crops, according to the Swedish Bioenergy Association, Svebio [22].

3.3. Energy crops

Energy crops represent an alternative for farmers for environmental and economic considerations. A number of perennial energy crops are available, including willow and poplar, as well as perennial energy grasses, such as miscanthus and reed canary grass, which can be used for solid biofuel or biogas production. But the winter persistence of miscanthus is low, and till now there is hardly any commercial cultivation of this species. In the Nordic countries, the yield of reed canary grass is about 4–7 tonnes dry matter/ha when harvest losses are taken into account [25] and the average yield of willow is about 5–6 tonnes dry matter/ha, depending strongly on site conditions [26]. Energy crops are cultivated in Nordic countries in a limited amount, mainly short rotation willow in Denmark and Sweden and reed canary grass in Finland. Finland and Sweden plan to increase the area of energy crops, as well as biofuel production based on grain and oilseed crops. There are several biogas plants based on animal manure, but only a few are using energy crops such as silage maize or grass silage as a substrate [13,25]. There is no commercial cultivation of agricultural crops for energy purposes in Norway. Reed canary grass is grown to some extent for forage production. For the moment, there are no prospects for a significant increase of energy crop cultivation in the near future. So far some research has been carried out for reed canary grass and willow for energy purposes [25]. As a part of a Norwegian project on production of biodiesel based on agricultural crops, the potential yields of different oil seed crops were examined in different regions of Norway [27].

The available land area for energy crops in Denmark is very limited. Presently, the area used for the cultivation of willow is only about 2000 ha [9,25]. According to the Energy Action Plan of 1996 (Energi21), the contribution of energy crops or other biomass, excluding straw, to the energy supply shall be increased to approx. 45 PJ in the year 2030, which is equivalent to approx. 500,000 ha willow [10]. Reed canary grass receives particular interest in Finland, due to the small labour requirements and no investment needed in new machinery [25]. The production of reed canary grass for energy production has increased from 8700 ha in 2004 to about 20,000 ha in 2008, and the area is expected to be 40,000 ha in a few years [23]. The target for cultivating reed canary grass in Finland is 100,000 ha in the long term. Up to 500,000 ha of agricultural land may be available for energy crops over the next decade, of which 100,000 ha are for energy grass and the rest for grain and oilseed crops [13].

Reed canary grass is cultivated for biomass for energy in Sweden, on a reduced area, less than 800 ha [22] and about 17,000 ha of Short Rotation Coppice (SRC) are currently cultivated with willow on arable land in Sweden. The area is no longer increasing, mostly because of reduced subsidies and low profitability, even if higher yields (up to 20 tonnes dry/ha) might be achieved with fertilisation [22,26].

4. Bioenergy market

4.1. Energy production and biomass use

The Nordic countries have a good record in bioenergy production and development of forestry technologies that can be used as examples of good practice by other EU Member States. Denmark, Finland, Norway and Sweden already have a significant part of their energy supply from renewable sources. The contribution of different renewable energy sources to energy consumption in Nordic countries is presented in Fig. 1 [8,14,28–31]. Norway has large resources of oil and gas and is a large producer of primary energy. The net energy consumption was about 864 PJ in 2008, representing only about 9% of the production of primary energy carriers [8]. Electricity has the highest contribution to the energy supply, amounting for 401 PJ, or around 49% of energy consumption. Norway has a leading position with a share of renewable energy of

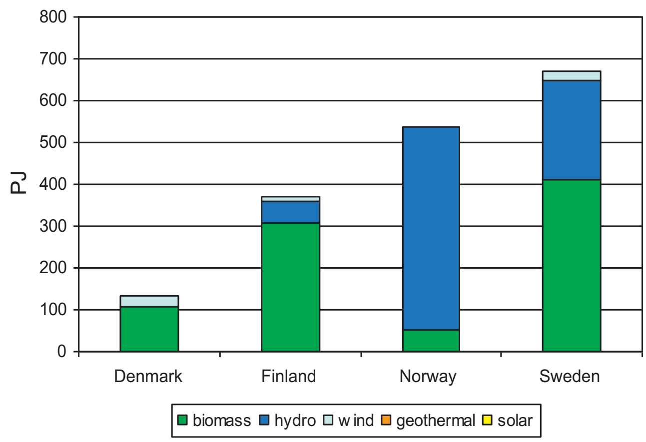


Fig. 1. Renewable energy sources in Nordic countries.

58% of gross energy consumption in 2008 due to the extensive use of hydro energy [15]. The abundance of hydro power and low electricity prices did not favour the increase of bioenergy production in Norway [8].

The total bioenergy consumption in 2008 in Norway was around 54 PJ, representing around 6% of the primary energy demand, mainly as waste and wood [5,8,31]. Bioenergy is mainly used in Norway within the forest industries (18 PJ), district heating (10 PJ) and in households (20 PJ), as firewood, wood briquettes and wood pellets [5,8]. Currently, the main contribution of biomass in Norway is for heat production in households (50%) and in forest industries (35%). The main sources of bioenergy are firewood used in households and wood residues and waste in district heating and forest industry [8]. The electricity production based on biomass is around 1.8 PJ produced from waste and residues from pulp production [8,22]. Bioenergy covers around 25% of energy demand in the wood processing industry. The energy is used for heating, as process energy, or for electricity production. Sawmills and the wood processing industry use most of the wood by-products, black liquor and waste wood for internal use for heating, process energy or electricity production [24].

Denmark is a world leader in bioenergy production from straw, municipal waste and biogas from animal manure. Renewable energy production has experienced a significant growth in the last decades, its share in the primary energy consumption increasing from over 6% in 1990 to 16.5% in 2008. Renewable energy contributed 143 PJ to the energy supply in 2008, compared with the gross energy consumption of 864 PJ [9,28]. Renewable energy accounted for about 26.5% of the total gross electricity production. Biomass is largely used in power plants and in smaller biomass-based cogeneration of heat and electricity [18,22,28,32]. Biomass provides a major contribution to renewable energy in Denmark, with more than two thirds of renewable energy production for heat and electricity generation [22,28,32]. The use of biomass for energy production increased from around 24 PJ in 1980 to 107 PJ in 2008. Biomass used for energy in 2008 accounted for 13% of gross inland energy consumption [29]. Wood contributes with approximately 65 PJ to energy production, the rest consisting of organic waste (22 PJ), straw (15.6 PJ) and biogas (4 PJ). Around 45% of the bioenergy production from wood comes from firewood, about 28% from wood pellets, 17% from wood chips and the rest from wood waste [9,22,28]. Firewood is almost exclusively used in Denmark in households, wood chips and wood waste in large district heating and power plants, while wood pellets are used in households, district heating and power plants. A further increase of biomass, comprising wood chips, straw and wood pellets, is expected for combined heat and power plants, primarily due to the policy agreement of 2008 [9,33].

Finland is one of the world leaders in bioenergy production and technology. The total energy supply in Finland was about 1414 PJ in 2008, with a major share of 27.8% of total energy supply from renewable energy sources. The development of the forest sector encouraged the use of biomass for energy purposes [11]. Bioenergy represents 77% of total renewable energy in Finland, with 302 PJ originating from biomass out of a total 393 PJ [22]. Biomass covers around 21.4% of the total primary energy consumption in 2008 (302 PJ out of 1414 PJ) and 12.9% of electricity production (the highest in the EU) [22,30]. Wood and peat are the most important sources of bioenergy, with over 95% of bioenergy production, with the rest generated from agricultural biomass, waste, biogas, and liquid biofuels [11]. In Finland forest-based bioenergy comes mainly from by-products of the pulp industry as black liquor (52%), other by-products from the pulp and sawmill industries (32%) and wood, stumps and logging residues (16%) [14 = 13]. Biomass is mainly used in the forest industry, in households and in heat and power generation. The forest industry is a major consumer of wood fuels, using almost two thirds of the wood fuel. Firewood has been always the most important source of energy for households. The use of wood fuels in heating and power plants has steadily increased [11].

The energy supply amounted to 2200 PJ in Sweden in 2008. The composition of the energy supply has changed significantly in the past decades. Natural gas supply, biomass (including peat and waste etc.) and wind power have significantly increased. Nuclear power and biomass have mainly replaced oil in energy generation. The share of renewable energy sources in Sweden for total energy supply has increased rapidly during the past decade, from 22% of the total energy supply in 1994 to more than 30% in 2008. In the final energy consumption, the share of renewable increased from 33.9% in 1990 to 44.1% in 2008 [13]. Renewable energy sources include mainly biomass, hydro and wind power.

The total bioenergy production in Sweden, including waste and peat, contributed with 443 PJ to the energy supply in 2008, about 20% of primary energy supply, one of the highest shares in the European Union. Biomass is used mainly in the forest industry, in district heating, for electricity production and for heating of residential buildings. Forest industry used almost 187 PJ, the residential and service sectors used 50 PJ, and the transport sector used 16 PJ [14]. About 142 PJ were used for district heating production, and 48 PJ for electricity. Biomass provided about 50% of the heat supply, 10% of electricity and 4% of transport fuels in 2008 [14,22]. The major part of biomass used for energy originates from logging residues and firewood, as well as wood by-products and black liquor from the pulp and paper industry and wood pellets and briquettes [13,14,22]. Energy crops such as short rotation coppice (willow) or energy grass (reed canary grass) have only a limited contribution to bioenergy production, with 17,000 ha for willow and 800 ha for reed canary grass [25,34]. In pulp mills, most of the process energy comes from the black liquor, wood wastes and wood chips. About 1,850,000 tonnes of wood pellets are also used in households and in the service sector [21].

The current use of biomass and the estimated potential for bioenergy in the Nordic countries are presented in Fig. 2 [5,7,10,13,22]. The different biomass sources in the energy supply are presented in Fig. 3 [8,9,11,16,20,35].

4.2. Biofuels

On average, liquid biofuels accounted for 3.4% of the energy consumed in transport in 2008 in the European Union. However, the situation is very diverse among Member States. Sweden has a leading position in the share of biofuels in transport with 4.8%, while the same share is 2.2% in Norway, 1.9% in Finland and only

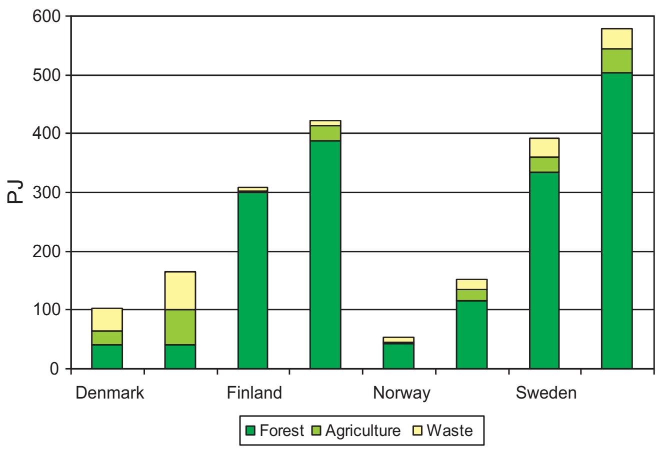


Fig. 2. Estimation of current use and potential bioenergy.

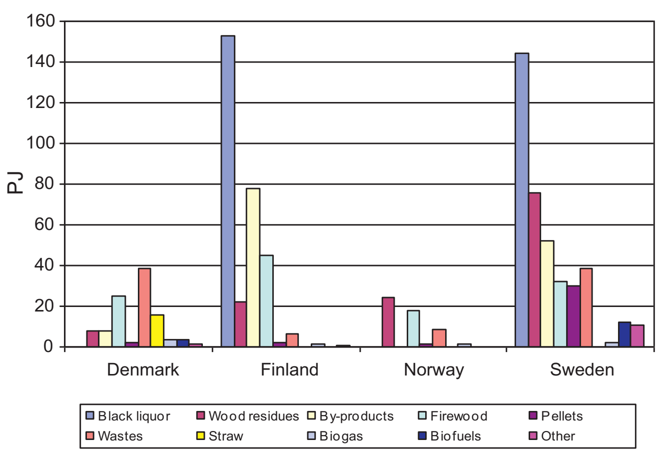


Fig. 3. Different biomass sources in the energy supply.

0.1% in Denmark (Table 2) [29,36]. Biofuel production in Norway is still at early stages. The production of biodiesel in Norway is based mainly on imported rapeseed. Bioethanol is not produced in Norway and the consumption of bioethanol is still very limited [8]. The use of biodiesel is growing rapidly in Norway and increased from 31,000 toe in 2007 to 76,000 toe in 2008 which is about 4% of the total diesel consumption for transport [31]. Several large biodiesel production plants are being constructed or planned in Norway.

Denmark has a growing production of biodiesel based on rapeseed, reaching 89,000 toe in 2008 [29]. The major part is not used in Denmark, but exported mainly to Germany and Sweden, where tax exemptions on biofuels provide better market conditions [7,22].

Despite the reduced domestic consumption of biofuels in road transportation in Finland, the production of transport biofuels, primarily biodiesel from vegetable oils and animal fats, has increased to 10,000 toe in 2008. Finland has a small but rapidly growing market for bioethanol, increasing the imports of bioethanol from

Table 2
Biofuels share in road transport [%].

	2003	2004	2005	2006	2007	2008
Denmark	0.0	0.0	0.0	0.1	0.1	0.1
Finland	0.1	0.1	0.0	0.0	0.0	1.9
Sweden	1.1	2.0	1.9	2.6	4.0	4.8
Norway	0.0	0.0	0.0	0.1	0.9	2.2
EU	0.5	0.7	1.1	1.9	2.6	3.4

Table 3
Biofuels for transport [thousand toe].

	2003	2004	2005	2006	2007	2008
Production						
Denmark	40	58	63	63	63	89
Finland	0	0	0	0	0	10
Sweden	76	160	218	319	430	463
Norway	–	–	–	–	–	–
EU	1445	2205	3821	6273	8824	10,204
Consumption						
Denmark	0	0	0	4	6	5
Finland	4	5	0	1	1.8	85
Sweden	76	142	135	188	285	372
Norway	0	0	0	5	31	76
EU	1421	1980	3120	5517	7821	10,077

1143 tonnes in 2002 to 73,800 toe in 2008 [36]. Two plants with a capacity of 200,000 tonnes/year each are in operation for biodiesel production, using vegetable oils and animal fats [11].

Sweden has a leading position in the EU in terms of biofuels consumption for transportation. Final energy use of renewable fuels in transport increased from 22,000 toe in 2000 to 372,000 toe in 2008. The major part of biofuels used in 2008 in Sweden consisted of bioethanol with 214,000 toe and 138,000 toe biodiesel [29]. Biogas is used both as a cleaned biogas and mixed with natural gas for electricity, heat generation or transport. In 2008, the transport sector used 28,000 toe of biogas [14,29,36]. Biogas was produced in 223 biogas plants in 2006 from waste, sewage sludge, and landfill [14]. Table 3 shows the evolution of biofuels production and consumption in transport in the Nordic Countries [36].

4.3. *Wood pellets*

The importance of wood pellets for small and medium scale heat production and large scale power generation is increasing in Europe. The annual pellet production in Europe amounted to more than 7.5 million tonnes in 2008 [21]. In Norway and Finland, the support provided to the domestic pellet production has led to an increase in production capacity and finally to overcapacity, while the pellet consumption remained low [15]. Table 4 shows the wood pellets production and consumption in Nordic countries [21].

Compared to the neighbouring countries, the production and consumption of wood pellets in Norway is rather small. The production capacity is more than 160,000 tonnes, however this capacity has been used to a limited extent. Pellets are used for heating purposes in the residential sector in stoves in some larger boiler plants and in a few district heating systems. In 2008 the Norwegian pellet production was 35,000 tonnes and the consumption amounted to 40,000 tonnes of wood pellets [21]. Wood pellet production is expected to grow from 35,000 tonnes to around 500,000 tonnes within a few years as the result of increased production capacity.

Wood pellets consumption has increased significantly in Denmark during the last several years. Wood pellets are used

Table 4
Wood pellets in Nordic countries [thousands tonnes].

	2003	2004	2005	2006	2007	2008
Production						
Denmark	177	187	187	137	149	134
Finland	185	185	190	265	335	370
Norway	20.3	33.6	42.3	51.3	44.8	35.1
Sweden	870	95	1100	1458	1400	1405
Consumption						
Denmark	580	731	820	795.6	990	1060
Finland	35	45	55	87	115	150
Norway	15.3	22.1	19.5	30.2	31.9	39.8
Sweden	1140	1220	1480	1680	1720	1850

for space heating in households, public and other large buildings. Wood pellets are being used in all sizes of combustion plants: pellet stoves and small boilers in single family houses, small block central heating, medium and large district heating plants and large power plants. In 2008 the total consumption of wood pellets was 1,060,000 tonnes. The national production of around 300,000 tonnes per year was able to cover only a small part of the demand. Wood pellet production in Denmark is to a large extent based on dry wood residues from the numerous wood processing industries. As the wood pellet production is decreasing due to feedstock availability and as the demand has increased rapidly, Denmark has become a large pellet importing country [21].

Pellet production has increased steadily since 1998 in Finland, reaching 376,000 tonnes in 2008. The total production capacity in Finland was around 680,000 tonnes in 2008. In contrast to the fast growth on the supply side, domestic consumption of wood pellets has grown slowly in Finland up to around 150,000 tonnes in 2008 [11,21]. Finland is thus a major pellet exporting country. The majority of Finnish pellet production has been exported, representing about three quarters of total production. Pellets are exported to Sweden (45%), Denmark (31%), the United Kingdom (10%) and Belgium (8%) [11,22]. The Swedish wood pellet market is one of the largest in the EU. A number of pellet factories have been established, with a total production capacity of around 2.2 million tonnes in 2008 [7]. The actual production was around 1.5 million tonnes, while the total consumption was around 1.85 million tonnes. Wood pellets are used in large district heating plants and CHP plants. In 2008, around 4000 boilers were in operation in Sweden. Around 120,000 households had pellet boilers and 20,000 had pellet stoves. Sweden is also a large wood pellet importing country. Sweden has imported around 350,000 tonnes in 2008, mainly from Canada, Poland, Finland and the Baltic States [16,21].

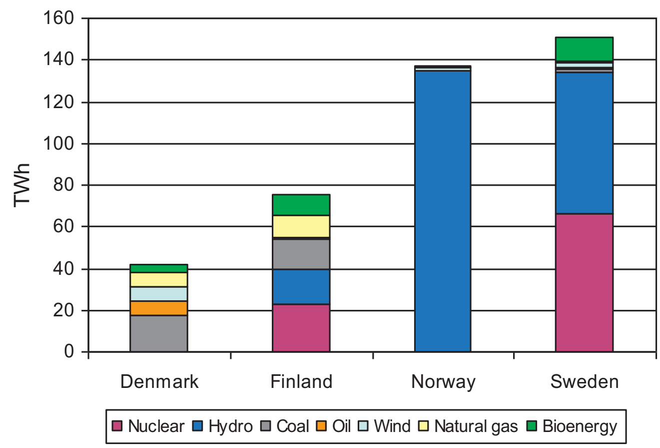


Fig. 4. Electricity supply in Nordic countries in 2008.

5. Bioenergy production

5.1. Electricity generation

The main uses of biomass in Nordic countries are for electricity production and heat generation. However, there are large differences between the Nordic countries in terms of the level of renewable electricity generation and the role of bioenergy [15]. The share of biomass in electricity generation has increased over time. Almost all the electricity in Norway (142 TWh) produced in 2008 was from hydro sources with 135 TWh, or 98.5% of the total electricity generation. Bioenergy constitutes a minor share of renewable electricity, increasing from 242 GWh in 1994 to 443 GWh in 2007, representing less than 1% in total electricity production. Wind power also accounts for about 900 GWh in 2007. Solid biomass contributes approximately 317 GWh, (72% of bioenergy electricity), while 115 GWh originates from municipal waste and 11 GWh from industrial waste [15].

In 2008, total electricity supply in Denmark was 36.4 TWh, of which 10.4 TWh was from renewable sources, representing 27.7% of electricity supply, with the greatest contribution from wind power (70%) and about 30% from biomass [28]. The use of biomass for electricity production in Denmark increased significantly from 0.21 TWh to 10.4 TWh between 1990 and 2008. The use of wood for electricity generation has increased significantly since 2001 and is today responsible for 1.2 TWh (42%), compared to 1.1 TWh electricity from municipal waste (38%) and 0.6 TWh electricity from straw (20%) [28]. Wood pellets account for the major part (57%) of wood use for electricity production followed by wood chips (33%) and wood waste (9%). Biogas, produced from landfill, sludge and other sources, provided 0.9 TWh of electricity production [28,33].

In 2008, total electricity consumption in Finland amounted to 87.2 TWh. From the 74.5 TWh of domestic production, 36% was produced from renewable energy sources, 30% with nuclear power and 27% from fossil fuels. From renewable energy, 16.9 TWh was produced from hydro and 9.6 TWh from biomass and 0.3 TWh from other sources. Of the renewable sources, the main contribution was made by hydro (62.5%) and the rest by black liquor (19.5%), wood (16%) and other renewables. Finland has, in 2008, the second position in the EU, after Germany, for electricity production from biomass, representing 12.9% (9.6 TWh), of which 5.3 TWh from black liquor and 4.3 TWh from wood [30,36].

The electricity use in Sweden increased in the last decades due to a high demand from energy intensive industries, a high proportion of electric heating and low electricity prices. In 2008, total electricity use in Sweden amounted to 146 TWh. The share of renewable electricity in the total electricity supply increased during the last decades. Electricity production from renewable sources amounted to 83.7 TWh in 2008, representing 57% of the total production, of which hydro accounted for 68.4 TWh, biomass (including peat and waste) 13.3 TWh and wind power 2 TWh. Bioenergy represents a major source of renewable electricity apart from hydropower, increasing its share from 3% in 1994 to 9% in 2008 [14]. Biomass electricity increased from 2 TWh to 13.3 TWh between 1990 and 2008, of which wood and wood wastes have the major contribution. Waste is also an important source for electricity with a production of 1.2 TWh and electricity production from peat amounted to about 1.1 TWh [15]. The electricity supply in Nordic countries in 2008 and the contribution of different sources are presented in Fig. 4 [14,28–31].

5.2. Heat generation

Biomass represents the main renewable resource for heating in Demark, Finland and Sweden [7]. The contribution of bioenergy to heat production varies across the countries. Sweden leads in terms of absolute use of biomass in heating. Bioenergy represented 48% of district heating in Sweden, 15% in Finland, 11% in Denmark and 7.6% in Norway [15]. The heat supply in is given in Fig. 5 [14,15,28,30,31,33].

In Norway, heat is provided mainly from electricity, which accounts for 82.3% of total energy use for heating in 2008. The share of district heating accounted for 11.5% of total energy use in buildings. Other energy sources are also used, although they have only a minor role, such as such as oil (2.8%), gas (0.8%), wood and wood pellets (2.1%). Half of the industrial buildings have central heating systems using electrical, wood boilers or other equipment for local heating, and 15% of them use district heating and 10% heat pumps

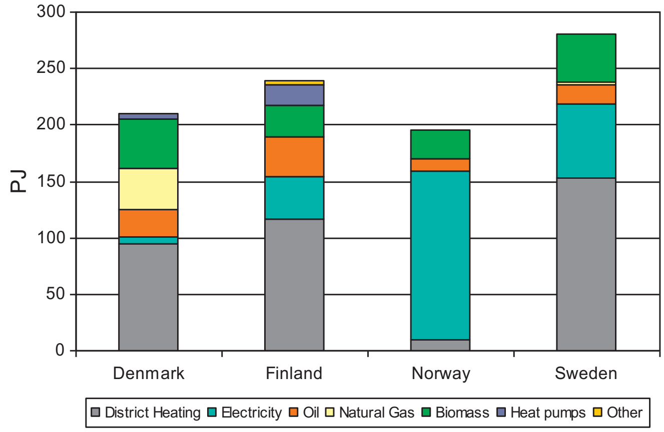


Fig. 5. Heat supply in Nordic countries.

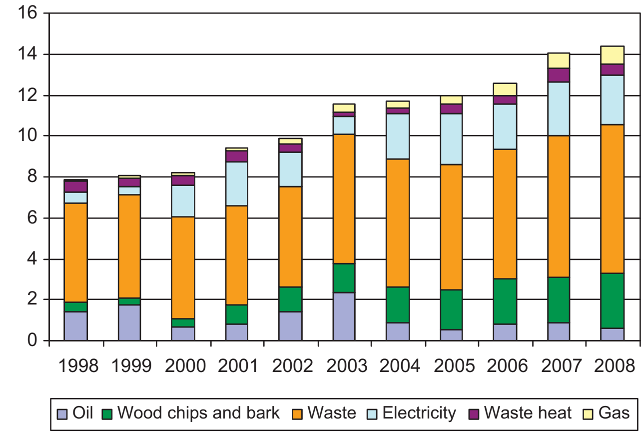


Fig. 6. District heating in Norway.

[33]. In Norway, most of the total biomass consumption of 54 PJ in 2008 was used for biomass heating [8]. The wood based heating increased since the 1990s, from approximately 12 PJ to 47 PJ in 2007 [15]. A large share of biomass came from firewood used for heating in households (18.1 PJ), forestry residues (17.9 PJ), waste in district heating (6.9 PJ), wood chips in district heating (2.3 PJ), wood briquettes (0.7 PJ) and pellets (0.6 PJ) [8]. The use of waste for heating has increased from approximately 12.6 PJ in 1990 to approximately 18 PJ in 2008 [15].

The heat supply for space heating in Denmark comes mainly from district heating (45%), individual and central systems. Besides the district heating, heat is provided by biomass, individual systems using solar energy, heat pumps, stoves or electric systems and through central systems using mainly natural gas and oil. The heat supply in 2008 in Denmark was around 210 PJ, with the main contribution from renewable (48 PJ), natural gas (37 PJ), oil (23.5 PJ) and electricity (6 PJ) [28]. The spread of district heating and the Biomass Agreement of 1993 in Denmark have contributed to the development of biomass heat production [15]. Biomass heating has increased significantly from around 15 PJ in 1990, to 48 PJ in 2008. Nowadays, bioenergy provides a major contribution to space heating (89%) the rest being supplied from heat pumps (9.5%), solar (6.5%) and biogas (1%). The main sources of bioenergy for space heating come from wood (56%), wood pellets (19%), straw (5%) and wood chips (0.5%). Heat production from biogas has also increased significantly, from 127 TJ in 1990 to 0.9 PJ in 2008 [15].

District heat provides a high share of about 48.6% of space heating in residential, commercial and public buildings in Finland, amounting to 106 PJ. Space heating for residential, commercial and public buildings was provided in Finland from district heating (48.6%), electricity (15.9%), wood (11.7%), oil (15.1%), heat pumps (7.3%), etc. [30]. Overall, heat supply in Finland is produced from biomass (20%), oil (18%), electricity (16%), natural gas (16%), coal (11%), peat (9%), heat pumps (7%) and other sources. Heat supply from bioenergy increased from about 4.4 PJ in 1992 to 42 PJ in 2008. Main sources for biomass use for heating are wood fuel, black liquor, industrial and recently municipal waste and biogas. Heat is supplied in Finland mainly through district heating for about 11.2% of 1.5 million buildings. In addition, electricity is used for heating 38% of the buildings, oil 22.7% and wood and peat 19.5% [30].

Sweden is leading in the use of biomass for heat generation. In the residential and service sector about 310 PJ is used for space heating and hot water production. The electricity use for space heating in the residential and service sector is important, amounting to 76 PJ in 2008, of which 50 PJ in individual buildings. In individual houses, 41 PJ of biomass, 15 PJ of district heating, 9 PJ of oil and 0.7 PJ of gas were used for space heating. Half of the heat requirement of residential and commercial buildings is provided by different individual heating systems. A common form of heating in individual houses is electric heating, used in about a third of individual houses. Using wood for heating is most common among households in agricultural or rural areas in Sweden. Heating is supplied by biomass to about 13.5% of the individual buildings, district heating to 9% and oil to 3.3% of the individual buildings [14,35]. Biomass is used as a heating source, for about 10% of individual houses. Most of this was in the form of split firewood, with a smaller proportion of wood chips and pellets and briquettes. Biomass is used to a much lesser extent in the large residential (0.7 PJ) and non-residential buildings (2.1 PJ). Large residential and non-residential buildings mainly use heating from district heating with the rest being supplied by electricity, oil or gas.

5.3. District heating

Denmark, Finland and Sweden have a well-developed infrastructure for district heating, as well as combined heat and power plants and heat plants that can use bioenergy. Norway has a less extensive infrastructure for district heating, limited to large cities. District heating accounts for about 1% of the total energy consumption in Norway [5]. The consumption of district heating has increased from 0.7 PJ in 1983 to 10.5 PJ in 2008, mainly in the service sector (6.9 PJ), in industry (1.2 PJ) and in households (2.4 PJ) [8]. Biomass is used in Norway primarily to produce heat and less than 20% of total biomass was used for district heating generation in 2008. Around 14.4 PJ of biomass, mainly waste and wood residues were used in 2008 for the production of district heating [8]. The major part of district heating was generated in waste plants, oil boilers, wood waste plants, electric boilers, heat pumps, gas plants and as waste heat [31]. Waste is the largest single fuel for district heating, amounting to 7.2 PJ in 2008, of which about 50% is renewable waste [5]. In addition, the use of wood accounted for 2.7 PJ (18.8%), electricity for 2.4 PJ (16.8), natural gas 0.9 PJ (6.3%), oil 0.6 PJ (4%), and waste heat 0.5 PJ (3.8%) [5,6,31]. District heating is expected to increase significantly as networks are planned in many cities, based, to a certain extent on biomass and waste [20]. The supply of district heating in Norway is presented in Fig. 6 [15,31].

Denmark has a long tradition in district heating, starting in 1930s. Denmark has an extensive district heating sector, supplying 98 PJ in 2008, representing more than 45% of the heat demand in 2008 [33]. The major contribution to the 36 PJ of heat generated from bioenergy in district heating in 2008, came from organic waste, with 15 PJ (41%) from wood, wood chips, wood pellets and wood waste (13 PJ or 35%), straw (5.8 PJ or 16.2%), bio oil and bio-

gas (2 PJ or 5.4%) and geothermal, solar and heat pumps with 2 PJ (2.7%) [28]. Around 1.5 million buildings in Denmark are heated from district heating, or around 60% of households. Biomass is used for heating in 120 straw and wood-based district heating plants, 10 straw or wood-chip-fired decentralised CHP, 30 waste-incineration plants, 6 biomass co-firing centralised CHP and 30 biogas CHP [33].

District heating in Finland is used on a large scale in most towns and densely populated areas. District heating has become the most important form of space heating, covering almost 49% of the heating energy in buildings in 2008 and supplied about 108 PJ, of which 19.8 PJ came from renewable sources. Residential buildings accounted for 56% of the district heat consumption. More than 90% of the heating requirements of the buildings in large cities in Finland are covered by district heating. District heating systems provides heat to about 2.6 million people in 1.2 million households. Almost 95% of apartment buildings and most public and commercial buildings are connected to the district heating networks [37]. In individual houses, just over 6% of the heating energy comes from district heat [37]. Biomass is being used on a large scale in the district heating sector, mainly in co-firing with peat in large plants [11]. Wood fuels accounted for 16.5% of the fuel supply in district heating systems, and peat accounts for 18.3% in 2008 [11,30].

Sweden has a well-developed district heating sector, accounting for almost 50% of the heating market in Sweden. District heating supplies residential commercial and industrial buildings with heat for both space heating and hot water. About 245 out of 290 municipalities are supplied with district heating generated from biomass [7]. Over 173 PJ of district heating was supplied in 2008. District heating supplies heat to about 82% of apartment buildings, about 66% of commercial buildings and approximately 9% of detached houses. The proportion of biomass in district heating has increased steadily since the 1970s, from 2% to 71.7% in 2008 using wood fuels, black liquors, tall oil pitch and peat [14]. About 200 district heating plants used biomass for heat production. Most of the wood fuels used are logging residues and by-products from the forest industry. Wood pellets are also increasingly used in district heating, both in small and medium sized boilers and district heating plants and large CHP and district heating plants [16,21].

5.4. Small-scale heating

Firewood has been traditionally a major fuel for heating in households in Norway. About 60% of the households use firewood for heating, mainly in wood stoves [8]. Firewood constitutes currently about 40% of the bioenergy market in Norway [5]. Due to low electricity prices, electric space heating dominates. The share of electricity use for space heating and hot water in households is estimated to be about 40% [5]. Norway has a very limited use of thermal heating in households compared to other Nordic countries [20]. For individual heating in Denmark, there are about 500,000 wood stoves, 70,000 wood boilers using firewood or wood chips, 30,000 wood pellet boilers and 9000 straw boilers [33]. Biomass heating in individual houses amounts to about 40.7 PJ of a total supply of 45.7 PJ. Firewood has been always an important fuel for heating, providing 31% of the heat supply in 2008. The rest of the heat demand is provided by natural gas (25%), oil (20%), wood pellets (10%), straw (3.5%) and heat pumps (5%) [28].

Small-scale use of biomass for heating of individual houses in rural areas, has a long tradition in Finland. Firewood has been always an important fuel for heating and about 25% of the heat supplied to individual houses in Finland is provided by wood [11]. Electricity and oil meet the rest of the heat demand. Firewood is used in about 2.9 million stoves and fireplaces in 1.5 million single-family houses in about 60% of individual family houses [11]. Firewood and wood pellets are used in fireplaces, stoves and boilers. Wood chips are used mainly in boilers. Wood chips and wood logs are commonly used in central heating systems in farms and large buildings in about 250,000 boilers [11,30]. In 2008, about half of the wood pellet consumption in Finland took place in small boilers and wood pellets are used in approximately 20,000 small-scale pellet boilers [11].

Small-scale use of biomass for heating of single houses has a long history in Sweden as it has in Finland. The most common fuel in households is still firewood, although small-scale use of wood pellets has increased significantly in recent years in residential and service sector, reaching about 1.5 PJ. Wood pellets are used in around 120,000 households in pellet boilers and 20,000 pellet stoves in 2008. However, electricity is still used extensively for space heating [35].

6. Opportunities and challenges for bioenergy developments

In Denmark, Finland and Sweden, the key elements for bioenergy development have been the use of various instruments. Energy and carbon taxes complemented with quota obligations, tax reduction and exemptions, investment subsidies and feed-in tariffs for renewable electricity, support for technology development, created adequate conditions for bioenergy growth. The experience from Denmark, Finland and Sweden shows that long-term, stable policies are needed to initiate and build up a bioenergy market. The abundance and relatively low prices of energy (i.e. fossil fuels, electricity), and the high investment costs required for bioenergy prevented the increased use of bioenergy in Norway. Enhanced incentives and R&D support for bioenergy can increase demand for renewable energy and support the development of a bioenergy market.

Increased use of biomass requires higher mobilization and better use of biomass resources. Additional forest biomass may be harvested in Norway by more intensive management of currently exploited forests, including extensive planting, management of young forests and increased collection of forest residues. To some extent, it may also be possible to expand the harvest activities in new and remote areas to increase harvesting of biomass from forests currently not exploited for economic or technical reasons. However, there are several limitations relating to accessibility due to topography, infrastructure limitations and economic aspects. There are also concerns relating to sustainability issues if large scale biomass collection occurs, and limitations for harvesting in certain areas such as protected areas. The use of agricultural biomass is primarily limited to the use of residues due to the rather small Norwegian agricultural sector, with limited cultivation of energy crops. It is likely that a considerable part of this bioenergy from agriculture will be based on the use of wastes and residues from agricultural production and food industry. In addition to the biomass trade between Norway and neighbouring Nordic countries, there might also be some space in the future for imports of biomass from other European countries. This could also include some Mediterranean countries where there are large available agricultural areas [38].

The main barriers for bioenergy development rely in the lack of a real market for bioenergy and lack of infrastructure for heat and electricity. The availability of cheap electricity in Norway, mainly from hydro sources, is also one of the main issues preventing the development of the bioenergy sector. Other barriers are lack of know-how in the whole value chain for bioenergy, although valuable expertise exists in the neighbouring countries. Additional investments are necessary in developing the whole value chain for biomass supply and district heating networks and systems in buildings.

There is a full range of technologies available for biomass to heat or biomass to electricity production both at the small and

large scale for households, district heating and industry for using wood logs, wood pellets and briquettes and wood chips. There are market opportunities for individual heating in high efficiency and low emissions, pellet stoves, pellet boilers and firewood stoves. For small-scale heating applications, the greatest challenge lie in technology improvement and market development through which biomass use can become a convenient and competitive alternative to other heating options. Combined heat and power production for industry and district heating might become an efficient and cheap heating option. They can provide opportunities for modernisation of existing district heating plants and development of new district heating networks for switching from fossil fuels to biomass.

7. Conclusions

The bioenergy contribution to energy consumption in Denmark, Finland and Sweden is among the highest in Europe. The type of biomass resource used for bioenergy purposes reflects to a large extent the resource availability in that country, for example agriculture in Denmark and the forestry sector in Finland and Sweden.

The Norwegian bioenergy strategy aims to reach 100 PJ bioenergy by 2020, almost doubling the present figures. District heating is expected to increase significantly as networks are planned in many cities, to a certain extent based on biomass and waste.

In Denmark, Finland and Sweden, bioenergy policies have been successful, the use of biomass has grown significantly and bioenergy makes a large contribution to energy supply. There are now relatively large, functional markets for bioenergy. The development of different sectors was the result of various policies and support for developing a specific area and differences appear between Denmark, Finland, Norway and Sweden. For example, the growth has been strongest in Sweden where high carbon taxes, in addition to other policy measures, created a strong long-term confidence.

Various support schemes for bioenergy have contributed to the progress of biomass energy production technology and forestry machinery, supply chain development, organisation, markets and logistics for biomass use and in cost reductions. There is also a significant available potential for increasing the contribution of biomass resources to energy production. Despite a significant natural capital in Norway with significant wood resources, wood mobilization is difficult due to for example, topography and problems of access. The experience gained in Denmark, Finland and Sweden may be relevant for Norway, as well as for other EU Member States, where there is a deficit of mobilization of biomass resources and insufficient industrial integration of bioenergy with other forest-based sectors.

Conversion factors:

1 Mtoe = 41.868 PJ
1 PJ = 0.02388 Mtoe

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